SOFT HANDOVER TECHNIQUES

The present invention relates to soft handover
techniques for use in cellular communications systems.

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In a cellular mobile communications system, each base
station has associated with it a cell covering a
certain area (a "footprint"). A user equipment within
the coverage area of the cell communicates with the
10 system by transmitting radio signals to, and receiving
radio signals from, the base station associated with
the cell. The shapes and sizes of different cells can
be different and may vary over time. The respective
coverage areas of adjacent cells generally overlap with
15 one another so that at any given time, a user equipment
may be capable of communicating with more than one base
station.

If a user equipment is located in a region where two or
20 more cells overlap, then a soft handover may take place
between those cells. During soft handover, a user
equipment is in communication with two or more base
stations concurrently. Soft handover is used to enable
a controlled handover to take place when a user
25 equipment moves from one cell to another, and to take
advantage of overlapping cell coverage to increase
signal quality. If the user equipment remains in a
soft handover region, then it can continue to take
advantage of the base station diversity indefinitely.

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During soft handover, the user equipment maintains a
list of active base stations and candidate base
stations. The active base stations are those which are
involved in the soft handover operation, i.e. those to
35 which the user equipment transmits its data. The
candidate base stations are base stations of which the

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user equipment is aware, but which are determined not to be suitable for data transmission. In known soft handover techniques, the decision as to which base stations should be involved in the soft handover
5 operation is made based on measures of signal qualities in the respective cells. For example, the user equipment may measure the qualities of signals received from various base stations and use those measures to determine which of the base stations should be active
10 base stations. The selection of the active base stations is updated as the signal from one base station weakens and that from another base station strengthens.

In the known soft handover techniques, the selection of
15 a base station for soft handover is made based on the quality of the radio channel to the base station. However, it has been realised pursuant to the present invention that the base station selection process in soft handover can be made more effective by also
20 considering other factors. In particular, it may be desirable to consider the amount of congestion that is likely to occur in a cell when selecting a base station for soft handover.

25 In accordance with a first aspect of the invention there is provided a method of selecting an active base station for use during soft handover, the active base station being for receiving data from a plurality of user equipments, the method comprising:
30 determining the amount of data in the data buffer of each of the user equipments;
comparing the amount of data in the data buffers of the user equipments to obtain a relative indicator, the relative indicator indicating how full a user
35 equipment's data buffer is in comparison to the data buffers of the other user equipments; and

selecting a base station as an active base station in dependence on the relative indicator.

By selecting a base station based on the relative
5   amounts of data in the user equipment's buffers, it may be possible to take into account the amount of congestion that the base station may experience. For example, a base station which has many user equipments with relatively full buffers is likely to be receiving
10   large amounts of data, and that base station might therefore become congested. In this case the base station might be avoided. On the other hand, a base station which is likely to receive relatively little data is unlikely to be congested, and therefore might
15   be selected.

The relative indicator may be, for example, an indication of how full a user equipment's buffer is in comparison to the average, or an indication of how full
20   a user equipment's buffer is in comparison to the minimum. A plurality of relative indicators may be obtained for each user equipment, in which case both an indication of how full a user equipment's buffer is in comparison to the average and an indication of how full
25   a user equipment's buffer is in comparison to the minimum may be obtained. By using both of these values, the distribution of the various data buffers in terms of buffer occupancy can be taken into account.

30   A base station is in communication with all of the user equipments in its cell, and therefore the base station may be in the best position to compare the amount of data in the data buffers of the user equipments. Therefore the comparing step is preferably carried out
35   by the base station. However, the comparing step could be carried out elsewhere, such at an radio network

controller (RNC), or at the user equipments themselves, if appropriate.

If the base station carries out the comparing step, then the method may further comprise the step of transmitting the or each relative indicator for each user equipment from the base station to that user equipment. In this way, each user equipment is given some knowledge of the state of the buffer in the other user equipments. The step of selecting a base station may then carried out by the user equipment. Alternatively, the or each relative indicator may be transmitted to a radio network controller, and the step of the step of selecting a base station may be carried out by the radio network controller.

In order for the base station to compare the amount of data in the data buffers of the user equipments, it must have available the actual amount of data in each data buffer. In order to achieve this, in one embodiment, a user equipment determines an amount of data in its data buffer and transmits an indication of the amount of data to the base station. If all of the user equipments transmit the amount of data in their data buffers in this way, the base station is then in a position to determine the relative indicators.

In some circumstances be undesirable for the user equipments to be transmitting indications of the amount of data in their data buffers on a regular basis. For example, if many user equipments are present, or a large amount of data needs to be transmitted in the uplink, the extra transmissions involved in the reporting process may increase the amount of interference or congestion to an unacceptable level. Thus, in a second embodiment, a user equipment sends to

the base station an indication of the total amount of
data to be sent, and the base station determines the
amount of data in the user equipment's data buffer
based on the indication of the total amount of data,
and the amount of data already received by the base
station from that user equipment. This can reduce the
number of transmissions involved in the reporting
process in the uplink.

A base station may be selected as an active base
station based on a history of the or each relative
indicator. This can allow long term trends to be taken
into account, and may prevent spurious soft handover
decisions from being taken. However, most recent
values of the relative indicator(s) may be used as well
as or instead of the history.

Preferably a base station is selected as an active base
station based additionally on a measure of radio
channel conditions. This can allow a base station with
good radio channels conditions to be selected in
preference to one with poor conditions. A base station
may be selected as an active base station based on a
history of radio channel conditions, which may improve
the soft handover decision making process. For
example, if the history of the radio channels
conditions shows that the radio channel is getting
consistently worse, then it may be inferred that slow
fading is taking place, in which case that base station
may be deselected as an active base station. If the
history shows continuous swings between good and bad
radio channel conditions, then it may be inferred that
fast fading is taking place, and a base station which
is not experiencing such conditions may be selected as
an active base station in preference. If the radio
channel history show that a radio channel is getting

very rapidly worse, then that base station may be dropped immediately. On the other hand, a candidate base station which is getting consistently better may be selected as an active base station.

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The step of selecting a base station may be carried out by the user equipment, and the method may further comprise transmitting an indication of the selected base station from the user equipment to the base

10 stations. The indication may be, for example, an identification number of the selected base station, or a flag indicating whether or not a particular base station is selected.

15 In co-pending United Kingdom patent application in the name of Fujitsu Limited entitled "Virtually Centralized Uplink Scheduling" (agent's reference P100261GB00), the entire contents of which are incorporated herein by reference, an uplink scheduling technique is described

20 in which knowledge of the relative amounts of data in the buffers of the user equipments is used in scheduling uplink transmissions. To achieve this, the base station transmits a relative indicator to each user equipment, the relative indicator indicating how

25 full that user equipment's data buffer is in comparison to the data buffers of the other user equipments. The user equipments then schedule their uplink transmissions to the base station in dependence on the relative indicator which they receive.

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In a preferred embodiment of the present invention, the same relative indicator which is transmitted from a base station to a user equipment for the purposes of scheduling uplink transmissions is also used in soft

35 handover decisions. Thus the method may further comprise the step of scheduling uplink transmissions in

dependence on the or each relative indicator. For
example, each user equipment may determine a rate
and/or time at which it transmits data to the base
station based on the or each relative indicator for
that user equipment. If the relative indicator is
being transmitted anyway for the purposes of scheduling
the uplink transmissions, then using the relative
indicator when making soft handover decisions can allow
the decisions to be based at least partially on
anticipated congestion levels in a cell without the
need to transmit extra information from the base
station to the user equipment. In this way uplink
scheduling and soft handover can both be enhanced
through use of the same relative indicator which is
transmitted by the base station.

According to a second aspect of the invention there is
provided a base station for receiving data from a
plurality of user equipments, the base station
comprising:
        means for determining the amount of data in the
data buffer of each of the user equipments;
        means for comparing the amount of data in the data
buffers of the user equipments to obtain a relative
indicator, the relative indicator indicating how full a
user equipment's data buffer is in comparison to the
data buffers of the other user equipments;
        means for transmitting the relative indicator;
        means for receiving a signal indicating whether
the base station has been selected as an active base
station for a user equipment; and
        means for allocating a channel to the user
equipment if the base station has been selected as an
active base station.

The relative indicator may be an indication of how full
a user equipment's buffer is in comparison to the
average, or the relative indicator may be an indication
of how full a user equipment's buffer is in comparison
5   to the minimum. The comparing means may be arranged to
produce a plurality of relative indicators for each
user equipment.

The transmitting means may be arranged to transmit the
10   or each relative indicator for each user equipment from
the base station to that user equipment, or the
transmitting means may be arranged to transmit the or
each relative indicator to a radio network controller.

15   According to a third aspect of the invention there is
provided a user equipment comprising:
        a data buffer;
        means for transmitting to a base station
information concerning an amount of data to be
20   transmitted;
        means for receiving from a base station a relative
indicator, the relative indicator indicating how full
the data buffer is in comparison to the data buffers of
other user equipments served by that base station; and
25   means for selecting a base station as an active
base station based on the relative indicator.

The user equipment may further comprise means for
determining the amount of data in the data buffer, and
30   the information concerning an amount of data to be
transmitted may be an indication of the amount of data
in the data buffer. Alternatively, the user equipment
may further comprise means for determining an amount of
data to be transmitted in a call, and the information
35   concerning an amount of data to be transmitted may be

an indication of the amount of data to be transmitted
in the call.

The receiving means may be arranged to receive a
plurality of relative indicators from a base station.

The user equipment may further comprise means for
storing a history of the or each relative indicator,
and the selecting means may be arranged to select a
base station as an active base station based on a
history of the or each relative indicator. The
selecting means may be arranged to select a base
station as an active base station based additionally on
a measure of radio channel conditions. The user
equipment may further comprise means for storing a
history of radio channel conditions, and the selecting
means may be arranged to select a base station as an
active base station based on a history of radio channel
conditions.

The user equipment may further comprise means for
transmitting an indication of the selected base
station.

The user equipment may further comprise means for
scheduling uplink transmissions in dependence on the or
each relative indicator. The scheduling means may be
arranged to determine a rate and/or time at which data
is to be transmitted to the base station based on the
or each relative indicator.

The invention may also provide a communications system
comprising a base station according to the second
aspect and a user equipment according to the third
aspect.

In another aspect of the invention there is provided a base station which receives data from a plurality of user equipments, the base station comprising:

a processing unit which determines the amount of data in the data buffer of each of the user equipments, and compares the amount of data in the data buffers of the user equipments to obtain a relative indicator, the relative indicator indicating how full a user equipment's data buffer is in comparison to the data buffers of the other user equipments;

a transmitter which transmits the relative indicator;

a receiver which receives a signal indicating whether the base station has been selected as an active base station for a user equipment; and

a channel allocator which allocates a channel to the user equipment if the base station has been selected as an active base station.

In another aspect of the invention there is provided a user equipment comprising:

a data buffer;

a transmitter which transmits to a base station information concerning an amount of data to be transmitted;

a receiver which receives from a base station a relative indicator, the relative indicator indicating how full the data buffer is in comparison to the data buffers of other user equipments served by that base station; and

a base station selector which selects a base station as an active base station based on the relative indicator.

Features of any one of the above aspects may be applied to any of the other aspects. Method features may be provided with the apparatus aspects and *vice versa*.

5   In any of the above aspects, the various features may be implemented in hardware, or as software modules running on one or more processors.

The invention also provides a computer program or a
10 computer program product for carrying out any of the methods described herein, and a computer readable medium having stored thereon a program for carrying out any of the methods described herein. A computer program embodying the invention may be stored on a
15 computer-readable medium, or it could, for example, be in the form of a signal such as a downloadable data signal provided from an Internet web site, or it could be in any other form.

20 Preferred features of the present invention will now be described, purely by way of example, with reference to the accompanying drawings, in which:-

Figure 1 shows an overview of a cellular mobile
25 communications system;
Figure 2 shows parts of a user equipment in a first embodiment of the invention;
Figure 3 shows parts of a combined metric calculation unit;
30 Figure 4 shows parts of a base station in a first embodiment of the invention;
Figure 5 shows parts of a base station in a second embodiment of the invention; and
Figure 6 shows an example of the operation of an
35 embodiment of the invention.

Overview of a cellular communications system

Figure 1 shows an overview of a cellular mobile
communications system. The system is designed in
particular for use with the UMTS (Universal Mobile
5 Telecommunications System) Terrestrial Access Network
(UTRA) standard. The system consists of a number of
radio network subsystems (RNSs) connected to a core
network. The radio network subsystems handle all
radio-related functionality, while the core network is
10 responsible for switching and routing calls and data
connections to external networks. Each radio network
subsystem comprises a radio network controller (RNC)
connected to a number of base stations (BS). The base
stations manage the radio links with the user
15 equipments (UEs) within their area of coverage (cells).
The radio network controller manages the use of radio
resources of its cells; for example it is responsible
for hard handover decisions and load control.

20 Data is transmitted between the base stations and the
UEs over the air using code division multiple access
(CDMA). In CDMA, each channel to be transmitted is
spread over a wide spectrum using a unique spreading
code. At the receiver the received signal is despread
25 back to the original signal using a replica of the
spreading code. By using different spreading codes for
different channels, the various channels may be
transmitted simultaneously in the same frequency band.
Generally the spreading codes are chosen to be
30 orthogonal in order to minimise interference between
the channels. CDMA may be used in combination with
other multiplexing techniques, such as frequency
division multiplexing and time division multiplexing.
Each transmission channel may be one of a dedicated
35 channel (reserved for a single user), a common channel
(used by all users in a cell) or a shared channel
(shared between a number of users on a time division

multiplex basis). Beamformers may also be used in either direction to provide directional beams (space division multiplexing).

5 If a user equipment is located in a region where two or more cells overlap, then a soft handover may take place between those cells. For example, in Figure 1, UE2 is in an area served by BS1 and BS2, and thus can communicate with both of those base stations. During

10 soft handover, the user equipment maintains a list of active base stations and candidate base stations. It is then necessary for a decision to be taken as to which base station(s) are to be active base stations.

15 **Embodiments of the invention**
In embodiments of the invention, soft handover decisions are made based on both knowledge about the quality of the radio channel from the UE to the base station, and knowledge about the amount of data in the

20 buffers of other UEs in the same cell. In this way, the amount of congestion and competition faced by the UE from other UEs in the same cell is taken into consideration when making the soft handover decision.

25 Within a cell, each of the source UEs is grouped into a particular service group depending on the delay tolerance of the data that it is transmitting. The delay tolerance is a measure of the maximum acceptable time for a data packet to reach its destination. For

30 example, video services may have a low delay tolerance of, say, 100mS, while web services may have a relatively high delay tolerance.

During a soft handover event, each source UE determines

35 the amount of packet data existing in its buffer and waiting for transmission. Assuming the n-th source UE

belongs to the j-th service group with the same delay tolerance, each source UE divides this value by the maximum length of its data buffer to obtain a ratio of buffer occupancy, as follows

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$$Buffer\_Norm\_L_n(m) = L_n(m)/L_{max,j} \quad , \quad n=1...N_j \quad\quad (1)$$

where $L_n(m)$ is the amount of data in the buffer, the index m represents the current TTI or soft handover

10   event, N is the total number of source UEs in the cell, and $L_{max,j}$ is the maximum packet data buffer length which depends on the service group j. Each UE multiplies this value $Buffer\_Norm\_L_n(m)$ by 100 and takes the integer part to obtain a value referred to herein as

15   the buffer occupancy value. Each UE then sends this value to the base station. As an alternative the real numeric value between zero and one could be sent.

The base station receives the buffer occupancy value

20   from each UE served in the uplink. The base station is also aware of the maximum data buffer assigned to each service, and thus the base station can determine the amount of packet data that is currently waiting in each source UE's buffer for transmission. The base station

25   groups the source UEs according to their service class. It then determines the distance of the ratio sent by each source UE from the minimum ratio in each class, as follows

30    $$Distance\_min_n(m) = Buffer\_Norm\_L_n(m) - Buffer\_Norm\_L_{min,j}(m), \quad n=1...N_j$$

$$(2)$$

where Nj represents the number of UEs present in class j.

35

To increase the homogeneous behaviour of the metric, if desired, the distance from minimum value may be subject to a secondary normalised and mathematical mapping, by dividing the distance by the sum of all the distances.

Then the base station determines the distance of the ratio sent by each UE from the average ratio in a class of UEs. To do that the base station first determines the average received ratio as follows

$$Avg\_Ratio_j(m) = \frac{1}{N_j} \sum_{i=1}^{N_j} Buffer\_Norm\_L_i(m) \qquad (3)$$

If desired, this metric may also be subject to a secondary normalised and mathematical mapping, by dividing the average received ratio by the sum of all of the received ratios.

The distance from average is expressed as

$$Distance\_Avg_n(m) = Buffer\_Norm\_L_n(m) - Avg\_Ratio_j(m), n=1..N_j \qquad (4)$$

The base station converts the distance from minimum value and the distance from average value to two information bytes and sends them back to the source UEs in the current soft handover event.

It is assumed that the i-th source UE in soft handover mode is being served by a number of active and candidate base stations in the soft handover set.

$$SHO\_SET_i = \left\{ Active\_Node\_B_p, Candidate\_Node\_B_q \right\}, \quad p = 1 \cdots P \quad q = 1 \cdots Q \qquad (5)$$

where SHO_SET_i represents the set of active and candidate base stations, $Active\_Node\_B_p$ represents the p-th active base station, $Candidate\_Node\_B_p$ represents

the *p*-th candidate base station, *P* is the number of active base stations, and *Q* is the number of candidate base stations.

5   A UE which is in soft handover mode receives the distance from minimum and the distance from average values from two or more base stations. These values indicate how the UE stands in terms of the amount of data waiting to be transmitted in the uplink relative
10   to the other UEs in the cell to which they relate. These values can be expressed as follows

$$\text{Received\_Dist\_Min}_{n}(m) = \{Distance\_min_{n,p}(m), Distance\_min_{n,q}(m)\}$$

$$p=1...P, \quad q=1...Q \quad (\ 6\ )$$

15

$$\text{Received\_Dist\_Avg}_{n}(m) = \{Distance\_Avg_{n,p}(m), Distance\_Avg_{n,q}(m)\}$$

$$p=1...P, \quad q=1...Q \quad (\ 7\ )$$

The UE also creates a profile of the channel to each
20   base station, so that

$$\text{Channel}_{n}(m) = \{Ch_{n,p}(m), Ch_{n,q}(m)\} \qquad p=1...P, \quad q=1...Q$$

$$(\ 8\ )$$

where $Ch_{n,p}(m)$ is the knowledge about the quality of the
25   channel in the uplink from the *k*-th source UE to the *p*-th base station.

The distance from minimum and the distance from average values which are sent from the base stations involved
30   in soft handover are saved in separate buffers assigned to each of the base stations. In this way a history of the distance from minimum and distance from average values can be built up for each base station. These histories can be represented as follows

$$\textbf{Credit\_min\_History}_{n,p}(m) = \left\{ Distance\_min_{n,p}(m), \cdots, Distance\_min_{n,p}(m-L) \right\}$$

$$(9)$$

$$\textbf{Credit\_Avg\_History}_{n,p}(m) = \left\{ Distance\_Avg_{n,p}(m), \cdots, Distance\_Avg_{n,p}(m-L) \right\}$$

$$(10)$$

The result is a multiple congestion history buffering mechanism for the source UE.

The history of the quality of the channel between the UE and each base station is also saved, so that

$$\textbf{Channel\_History}_{n,p}(m) = \left\{ Ch_{n,p}(m), \cdots, Ch_{n,p}(m-L) \right\} \qquad (11)$$

where L is the length of history buffer.

The source UE studies the trend of the congestion history of all of the active and candidate base stations in all the surrounding and involved cells or sectors. The UE combines the congestions and channel histories to come up with a unique metric for each base station, as follows

$$Comb\_Metric_{n,p}(m) = Co \left(\begin{array}{l} \textbf{Channel\_History}_{n,p}(m), \textbf{Credit\_min\_History}_{n,p}(m), \\ \textbf{Credit\_Avg\_History}_{n,p}(m) \end{array} \right)$$

$$(12)$$

where Co is a function that combine these metrics. For example, the function Co may take the average of the values in each history and then multiply the various average values together. Alternatively or in addition, the function Co might calculate a trend of the values in each history, and then multiply the trends together. Any other appropriate way of combining the various

values could be used. The function *Co* may produce a single value, or a plurality of values. Combining the various histories in this way enables information concerning traffic congestion and radio channel
5 conditions in the uplink to be used in soft handover.

In soft handover mode, a UE is able to compare the base stations in terms of not only the quality of the radio channel but also the amount of traffic congestion the
10 base station handles, and the amount of competition the UE will face if it picks a certain base station. For example, a base station which is serving many UEs with full data buffers may be dropped from the active set. This may happen even if it has a fairly good radio
15 channel conditions compared to other existing active handover set members.

In order to schedule the uplink transmissions, the UE makes a final decision on the transmission format
20 including rate and waiting time based on a final metric which is a combination of received values from the involved active base stations in soft handover mode. This final metric is defined as

25 $$Decisive\_Metric_n(m) = Combination\left(\begin{array}{l} \text{Received\_Dis\_Min}_n(m), \text{Received\_Dis\_Avg}_n(m), \\ \text{Channel}_n(m) \end{array}\right)$$

$$(13)$$

The combination process *Combination* might be similar to the process *Co* used in the soft handover decision. However the *Combination* process does not necessarily
30 include the histories of the various values.

First embodiment
Figure 2 shows parts of a user equipment in a first embodiment of the invention. Referring to Figure 2,
35 buffer 10 receives data packets which are to be

transmitted and stores them on a first-in-first-out
basis. Packets for transmission are output from the
buffer 10 under control of scheduler 12.

5   A signal indicating the number of packets currently
stored is output from the buffer 10 to buffer occupancy
value calculation unit 14. This unit divides the
number of stored packets by the maximum length of the
buffer to yield the ratio of stored packets to maximum
10   buffer length, in accordance with equation (1) above.
The unit 14 then multiplies this value by 100 and takes
the integer part to give a value between 1 and 100,
referred to herein as the buffer occupancy value.

15   The buffer occupancy value calculated by unit 14 is
output to multiplexer 16. The multiplexer 16 inserts
this value into a control channel which is to be
transmitted in the uplink to the base station. An
output from base station selector 38 is also
20   multiplexed into the control channel. Packets output
from the buffer 10 are inserted into a data channel.
The combined signal is then given a channelisation code
by spreader 18, and transmitted to the base station by
means of transmitter 20, duplexer 22 and antenna 24.
25   Where the user equipment has two or more active base
stations, an appropriate channelisation code is used
for each base station.

The UE receives incoming signals by means of antenna
30   24, duplexer 22 and receiver 26. These signals are fed
to despreaders 28, which separate out control channels
which have been transmitted by the various base
stations involved in the soft handover process (both
active and candidate base stations). The control
35   channels contain control information for, amongst other
things, power control. In this embodiment the control

channels also contain the distance from average values
and the distance from minimum values transmitted by the
base stations involved in the soft handover process.

5   Channel quality indicators 30 estimate the quality of
the channels between the user equipment and the base
stations. Any suitable measure of quality can be
produced; for example, a received signal strength (RSS)
or power measure, a bit error rate (BER) or a frame
10   error rate (FER) measure, or a signal-to-interference
ratio (SIR) or a signal-to-interference-and-noise ratio
(SINR) measure could be produced. The measure could be
based on a pilot signal broadcast by the base station.
For example, the strength of the pilot signal could be
15   taken as a measure of signal quality, or the base
station may also broadcast the transmit power ratio of
a data channel to the pilot channel, and this ratio
could be used in conjunction with the pilot signal
strength to obtain a measure of signal quality.
20   Alternatively the measure could be derived from
transmission power control (TCP) information (such as a
power up/power down instruction) generated in the user
equipment for downlink power control purposes. Any of
the measures could be based on a history or average of
25   measurements taken over several measurement periods.
Two or more measures for each channel could be
combined, if desired. The outputs of channel quality
indicators 30 are fed to combined metric calculation
units 32 and decisive metric calculation unit 34.
30
Demultiplexers 36 separate the distance from average
values and the distance from minimum values from the
control channels, and pass these values to combined
metric calculation units 32 and decisive metric
35   calculation unit 34. Each of the combined metric
calculation units 32 combines the distance from average

value, the distance from minimum value and the channel quality value from one of the base stations in accordance with equation (12) above, to yield a combined metric for that base station. If desired,

5 more than one combined metric could be calculated for each base station; for example a first metric could be based on the latest values while a second metric could be based on histories of the various values. The various combined metrics are then fed to base station

10 selection unit 38.

Base station selection unit 38 selects one or more base stations as an active base station, based on the combined metrics. For example, if two base stations

15 have similar radio conditions, but one base station is serving many UEs with nearly full buffers, then the base station selection unit may select the other base station as an active base station. If two base stations are in a similar situation regarding the

20 buffers of the UEs which they are serving, then the base station with the best radio conditions may be selected as the active base station. If two base stations are facing similar conditions, then both may be selected as active base stations.

25

The output of base station selection unit is the identification number(s) of the selected base station(s). This number is multiplexed into the control channel(s) by multiplexer 16 for transmission

30 to the base stations. Alternatively the base station selection unit 38 may output a flag indicating whether a base station has been selected as an active base station. In this case the coding employed in the uplink tells the base station which UE the flag belongs

35 to.

Decisive metric calculation unit 34 combines the
distance from average values, the distance from minimum
values and the channel quality values to yield a final
metric, in accordance with equation (13) above. If
5   required, the number of stored packets value (output
from buffer 10) could also be used in calculating the
decisive metric. The decisive metric is output to
scheduler 12 for use in scheduling uplink data packet
transmissions. Where there are two or more active base
10   stations, the average of the decisive metric for all of
the active base stations could be used in making
scheduling decisions, or the value which gives the
highest transmission rate could be used, or some other
combination of the various values could be used. The
15   scheduling mechanism may be that described in co-
pending United Kingdom patent application entitled
"Virtually Centralized Uplink Scheduling" referred to
above. In this case, the distance from average values
and the distance from minimum values are used for both
20   soft handover and uplink scheduling.

The above reporting processes are repeated at
appropriate intervals. For example, the buffer
occupancy value may be calculated in the UE and
25   transmitted to the base station every Time Transmission
Interval (TTI). Similarly the distance from average
values and the distance from minimum values may be
calculated in the base station and transmitted to the
source UEs every TTI. Any of these processes may also
30   be carried out every two or more TTIs where
appropriate. For example, when the uplink channel
resources are fully utilised, or nearly fully utilised,
it may be desirable to reduce the amount of data which
is transmitted for the purposes of soft handover
35   decision making. In this case the reporting processes
may only take place every few TTIs. The intervals at

which the reporting processes take place may be varied,
for example, depending on traffic conditions in the
cell or sector.

5   Figure 3 shows parts of one of the combined metric
calculation units 32. Referring to Figure 3, combined
metric calculation unit 32A receives the distance from
average and distance from minimum values for a
particular base station from one of the demultiplexers
10   36 in Figure 2. These values are stored in distance
from minimum buffer 40 and distance from average buffer
42 respectively. The unit 32A also receives channel
quality indicator values from the corresponding channel
quality indicator 30 in Figure 2. The channel quality
15   indicator values are stored in buffer 44. Each of the
buffers has a length L and operates on a first-in-
first-out basis, so that it stores the previous L
values.

20   The outputs of the buffers 40, 42 and 44 are fed to
trend calculation units 46, 48, 50 respectively. Each
of the trend calculation units calculates a trend of
the data in the corresponding buffer. This may be
done, for example, by taking the differential of a
25   straight line fit to the data in the buffer, and then
mapping the value of the differential to a value
between zero and one. The outputs of the trend
calculation units 46, 48 50 are fed to average
calculation unit 52. The average calculation unit 52
30   calculates the average of the various trends, giving
weightings to the trends where appropriate. The output
of unit 52 is thus a value indicating an average trend
in the various histories. This output is fed to
multiplier 54.

35

The distance from minimum, distance from average and channel quality indicator values are also fed to average calculation unit 56. This unit calculates the average of the various values, using weightings where appropriate. The output of average calculation unit 56 is thus an average of the most recent distance from minimum, distance from average, and channel quality indicator values. This value is also fed to multiplier 54. In this example, the outputs of the two units 52 and 56 multiplied in multiplier 54, using weightings where appropriate, to give a single combined metric. This value is fed to the base station selector 38 in Figure 2. Alternatively the outputs of the units 52 and 56 could be fed separately to the base station selector 38.

The base station selector 38 uses a look-up table to decide which base station(s) should be the active base stations. As mentioned above, each user equipment maintains a list of active and candidate base stations. The base stations are ranked in the list in the order of the values of the combined metric. At any one time, the base station with the best combined metric is selected as an active base station. If there are another base stations with combined metrics that are nearly as good, then those base stations may also be selected as an active base stations. A total of, for example, three base stations may be active at any one time. However, if the next best base station is much worse than the best base station, then just the best base station may be selected as the active base station.

The list of active and candidate base stations is continually updated. Thus, if an active base station starts giving a poor combined metric, then it may be

dropped from the active list. In this case, the
candidate base station with the best combined metric
may replace the dropped base station in the active
list. In a similar way, base stations may be added to
5   or dropped from the list of candidate base stations.

Figure 4 shows parts of a base station in the first
embodiment. In operation, base station 60 receives
signals from antenna 61 and passes these signals to
10   duplexer 62. The duplexer separates received signals
from signals to be transmitted, and passes the received
signals to receiver 64. The receiver down-converts and
digitises the received signals, and passes the signals
to despreaders 66.
15

The despreaders 66 use the channelisation codes
employed in the uplink to separate the various channels
transmitted by the source UEs. Each of the despreaders
66 outputs a channel from a UE for which the base
20   station is an active base station. The choice of which
channelisation codes to use, and thus the choice of
which uplink channels to receive, is made by channel
allocation unit 68.

25   The outputs of the despreaders 66 are fed to
demultiplexers 70. Each of the demultiplexers 70
demultiplexes from the control channel of a particular
UE the identification number of the base station(s)
which that UE has selected to be an active base
30   station. The various identification numbers are fed to
channel allocation unit 68. If the base station 60 has
been selected as an active base station by a particular
UE, then the channel allocation unit 68 will allocate a
data channel for receiving data transmissions from that
35   UE. The base station will then only despread the data
channels for which it is an active base station.

However, the base station 60 may continue to receive control channels from a UE even when it has not been selected as an active base station. This can allow the base station to become an active base station if

5 required.

As an alternative to the identification number of a selected base station, a flag indicating whether or not the base station has been selected as active may be

10 received from each of the UEs. In this case the base station can tell to which UE the flag belongs based on the coding which has been used in the uplink.

The data packets received from the source UEs for which

15 the base station is an active base station are stored in buffers 72, one buffer being provided for each such source UE. The data packets are output from the buffers 72 in accordance with a scheduling routine for onward transmission to the destination UEs. Depending

20 on the location of the destination UE, the data packets may be transmitted to the destination UE in the base station's own downlink, or via a radio network subsystem or core network, or via the public switched telephone network, or via an IP-based network, or via

25 any other network.

The demultiplexers 70 also separate out the buffer occupancy values which have been transmitted by the source UEs. The buffer occupancy values are fed to

30 distance from average calculation units 74 and distance from minimum calculation units 76. Each of the distance from average calculation units 74 calculates the distance of the buffer occupancy value of one of the source UEs from the average buffer occupancy value

35 in that class, in accordance with equations (3) and (4) above. Each of the distance from minimum calculation

units 76 calculates the distance of the buffer occupancy value of one of the source UEs from the minimum buffer occupancy value in that class, in accordance with equation (2) above. The outputs of

5 distance from average calculation units 74 and distance from minimum calculation units 76 are therefore the distance from average values and the distance from minimum values respectively for each source UE.

10 The distance from average values and the distance from minimum values are fed to multiplexers 78. Each of the multiplexers 78 multiplexes the distance from average value and the distance from minimum value for one of the source UEs into a control channel that is to be

15 transmitted to that UE. The various control channels are then given channelisation codes by spreaders 80 and are transmitted to the source UEs by means of transmitter 82, duplexer 62 and antenna 61.

20 **Second embodiment**
In the first embodiment, a buffer occupancy value is sent from each source user equipment to the base station every soft handover event, which may be every TTI, or every few TTIs. However, in some circumstances

25 even reporting every few TTI may be undesirable because of the channel resources which are occupied. Thus, in a second embodiment of the invention, rather than transmit the buffer occupancy values to the base station every scheduling event, the base station

30 estimates the buffer occupancy values based on information transmitted to it at the beginning of a call, together with its own knowledge of how many packets it has received from a particular UE.

35 In this embodiment it is assumed that each UE is capable of determining the amount of packet data to be

sent at the beginning of packet call. Each UE then
sends this value to the base station. As communication
proceeds further, the base station estimates the amount
of data remaining in each UE buffer based on these
5   received values, and the number of packets that have
been received from each UE. The estimated values thus
obtained are then used to determine distance from
average values and distance from minimum values, as in
the first embodiment.
10

In the second embodiment the distance from average and
distance from minimum values are transmitted to the UEs
for use in uplink scheduling in the same way as in the
first embodiment. Thus this reporting process still
15   requires transmission to be made from the base station
to the user equipments on a regular basis. However,
since the present embodiments are concerned with
situations in which data is being sent from the user
equipments to the base station, the extra transmissions
20   in the downlink for the reporting process may not be
problematic.

A user equipment in the second embodiment is similar to
that shown in Figure 2 except that, instead of buffer
25   occupancy calculation unit 14, a total number of
packets indicator is provided which inserts into the
control channel at the start of a packet call the total
number of packets in that call.

30   Figure 5 shows parts of a base station in the second
embodiment. Those parts which are the same as in the
base station shown in Figure 4 are given the same
reference numerals and are not described further.
Referring to Figure 5, each of the demultiplexers 84
35   separates out the total number of packets value which
is transmitted by one of the source UEs at the start of

a packet call. These values are stored in call length
indicators 86. The data packets for onward
transmission to the destination UEs are output to
buffers 88, one buffer being provided for each
5   destination UE.

For each soft handover event, the number of packets
received from each UE in the current packet call is
output from the buffers 88 to number of packets
10   received indicators 90. The outputs of call length
indicators 86 and number of packets received indicators
90 are fed to buffer occupancy estimation units 92.
Each of these units estimates the buffer occupancy for
one of the source UEs. This may be done, for example,
15   by subtracting the number of packets received from the
total number of packets in a call for that UE. If
desired, account could also be taken of the rate at
which the UE buffer is expected to be filled.

20   The outputs of the buffer occupancy estimation units 92
are estimated buffer occupancy values for each of the
source UEs. These values are fed to distance from
average calculation units 94 and distance from minimum
calculation units 96. These units calculate the
25   distance from average and the distance from minimum
values for each class, in a similar way to units 74 and
76 described above with reference to Figure 4. The
outputs of distance from average calculation units 94
and distance from minimum calculation units 96 are
30   therefore estimated distance from average values and
estimated distance from minimum values respectively for
each source UE.

The thus calculated distance from average values and
35   the distance from minimum values are fed to
multiplexers 78 where they are multiplexed into a

control channel that is to be transmitted to that UE.
The various control channels are then transmitted to
the source UEs in the same way as described above with
reference to Figure 4.

5

If desired, a combination of the first embodiment and
the second embodiment could be used. For example, some
source UEs could report their buffer occupancies at
regular intervals using the first embodiment, while
10   other source UEs could have their buffer occupancies
estimated at the base station using the second
embodiment. Each UE may switch from one technique to
the other, for example, depending on channel
conditions.

15

Example
An example of the operation of the soft handover
mechanism in an embodiment of the invention will now be
described with reference to Figure 6. In this example,
20   soft handover is combined with an uplink scheduling
mechanism, such as the scheduling mechanism disclosed
in co-pending United Kingdom patent application
entitled "Virtually centralized uplink scheduling"
referred to above.

25

Referring to Figure 6, source UE A is evaluating two
available choices to deliver its data packets to
destination UE A. It is assumed that Node-B1 can serve
source UEs A, B, C, D. Source UEs A, E, F, G can be
30   served by Node-B2. It is assumed that UE A experiences
similar radio channel conditions and SINR (signal to
noise and interference ratio) from both Node-B1 and
Node-B2. It can be seen that, for the current TTI or
uplink scheduling event, source UE A has 85% of its
35   data buffer full. The equivalent value is 20% for UE
B, 30% for UE C and 10% for UE D. For Node-B2 these

values are 90% for UEs E, F and G. It is assumed that
all the source UEs support packet streaming real-time
service (e.g. real-time conversational video) with a
similar delay tolerance. In Figure 6, Ci1 represents

5   the distance from average value and Ci2 represents the
distance from minimum value received from Node-Bi. It
can be seen that UE A has received C11=49 which means
the amount of data in its buffer is well above the
average amount of all of the UEs served by Node-B1. UE

10   A also receives C12=75, meaning that it is far away
from the UE with minimum buffer data out of the UEs
served by Node-B1. At the same time UE A receives the
values C21= -3.75 and C22=0 from Node-B2. By looking
at these two values source UE A realises that, although

15   it has a buffer which is 85% full, it still has the
minimum buffer length among all the source UEs served
by Node-B2. Source UE A concludes that if it picks
Node-B2, it will face fierce competition from source
UEs E, F and G which already have full buffers. This

20   would lead to packet delivery delays and more traffic
congestion. However, if UE A picks Node-B1, then it
will face less congestion and less competition in the
uplink. This will also mean less interference for UE
A. Considering these evaluations and the fact that

25   source UE A experience similar radio conditions to the
two base stations, it picks Node-B1 as the active base
station.

Thus, in embodiments of the invention, a source UE is

30   made aware of its situation compared to other UEs
served by a given base station, in terms of packet data
congestion and the amount of existing competition for
radio channels in the cell or sector served by that
base station. By making this knowledge available to

35   source UEs from all the active base stations in the
active set, and making the UEs capable of combining

this information with soft-handover thresholds, better and more efficient soft handover is achieved. The credit history derived from congestion credit buffer allows the UE to look at the trend of packet data

5   congestion and competition for radio channels among all the source UEs served by any specific active or candidate base station. In this way the UE can make predictions about possible future candidates for being dropped from active soft handover set due to, for

10 example, increasing traffic congestion for that base station. If received credit histories from one base station, become worse and worse, the source UE will realize that this base station is becoming too congested and may be replaced by another candidate base

15 station which can handle packet data more efficiently and much faster. The result is a more efficient soft handover mechanism for wireless packet communications which will allow a better QoS and lower delays for continuous real-time streaming services such as real-

20 time conversational video service. In making a decision on active set of base stations, not only the received values from the base stations, also the knowledge available about the radio channel between a candidate base station and the source UE is involved.

25 This makes a packet-congestion-oriented-soft handover possible. The result is effectively striking a balance between the traffic load and radio channel conditions. In order to minimumize the amount of data sent as part of the reporting process, the reports can be sent or

30 received every couple of milliseconds by the UE and can be represented, for example, by only two bytes (16 bits).

Other embodiments

35 The RNC already has an idea about the nature of traffic load. This is a global knowledge and overlooking view

that the RNC has about the entire cellular area. In
view of this available information, as well as the fact
that other capabilities already exist in the RNC, it
might be preferred to leave the final soft handover
5   decisions to the RNC. If this is the case, and the
slow pace of information update at the RNC and its
timing mismatch to downlink scheduling timing can be
tolerated, and also the necessary communications for
transfer of uplink congestion credit values to higher
10   layers and extra network-layer overhead calculations
can be afforded by the RNC, an alternative approach is
to send the uplink multiple congestion credit values to
the RNC. The result is an uplink congestion-oriented,
combination of virtually centralised packet uplink
15   scheduler and soft handover, in which the final soft
handover decisions are being made by the RNC. However
major parts of the calculations related to this hybrid
process are distributed among the processors belong to
the base stations and the source UEs. In this case,
20   the RNC will be able to determine the Cell_Up and
Cell_Down commands and make soft handover decisions by
considering the uplink multiple congestion credit
values which are now available to it.

25   The various embodiments which have been described above
may be implemented using software modules running on a
processor, for example a digital signal processor, or
any other type of processor. The programming of such
modules will be apparent to the skilled person from the
30   description of the various functions. The skilled
person will appreciate that such modules may be
programmed on any appropriate processor using any
appropriate programming language. Alternatively, some
or all of the functions described above may be
35   implemented using dedicated hardware.

It will be understood that the present invention has been described above purely by way of example, and modifications of detail can be made within the scope of the invention. For example, the instead of

5   transmitting the distance from average values and the distance from minimum values for the base station to each user equipment, the base station may transmit signals indicating to each base station when and/or at what rate to transmit. The invention may be used with

10 multiplexing techniques other than CDMA, such as time division multiple access (TDMA), frequency division multiplexing (FDM), hybrid TDMA/CDMA, or any other appropriate multiplexing technique.